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EVALUATION OF DIGITAL COMMUNICATIONS USING THE MARINE CORPS COMMUNICATIONS ARCHITECTURE ANALYSIS MODEL

by

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September, 1992

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To assist in the transition, this thesis modified the Marine Corps Communications Architecture Analysis Model (MCCAAM) so it could measure

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Evaluation of Digital Communications Using the Marine Corps Communications Architecture Analysis Model

by

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ABSTRACT

The United States Marine Corps (USMC) is currently evolving to digital communications. This change has created a need for an analysis tool capable of analyzing digital architectures. Traditional communications are being supplemented, and in some cases, replaced by automated systems like the Marine Tactical Command and Control System (MTACCS). Older equipment, the PRC-77 and AN/VRC-12 family of radios, is being replaced by lighter, more efficient equipment like SINCGARS and the Digital Communications Terminal (DCT). Protocols like the Marine Tactical System (MTS) Broadcast Protocol are being implemented to orchestrate this new way of communicating.

To assist in the transition, this thesis modified the Marine Corps Communications Architecture Analysis Model (MCCAAM) so it could measure the impact of changing from voice to digital communications. The Fidelity Enhancement Process (FEP), a comprehensive methodology for model upgrades, was used to systematically modify the model. The model's usefulness is demonstrated in an analysis example by comparing three separate partially digital communications architectures.

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THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all the cases of possible interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they can not be considered validated. Any application of these programs without additional verification is at the risk of the user.

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

Digital communication is rapidly becoming the state of the art for both civilian and military applications. But, because of low budgets, survivability requirements and the transient nature of military communication, close attention has to be paid to the advantages and disadvantages of modifying existing communication structures. Is improved efficiency and reliability on a digital net worth the extra initiation and maintenance time the net may require? Does the problem of compatibility between types of nets and traffic sent become overwhelming when using a mixed architecture? The USMC is currently faced with these issues as it makes the transition to digital communication.

To understand the communication requirements of a Marine Air Ground Task Force (MAGTF), it is first necessary to understand its structure. All operational USMC units are deployed as MAGTFs of various shapes and sizes. From the smallest special purpose force to a Marine Expeditionary Force (MEF) composed of one or more Marine divisions, air wings and force service support groups, all MAGTFs contain four basic elements, a command element, a ground combat element, an air combat element and a combat service support element. Such a diverse organization, regardless of size, requires extensive

information flow to coordinate its efforts and ensure successful mission completion.

To make the most effective use of existing technologies to improve the warfighting capabilities of our forces, the USMC is developing the Marine Tactical Command and Control System (MTACCS). This is an umbrella system that integrates several separate automation-assisted MAGTF command and control systems to support tactical operations. Such systems include Tactical Combat Operations (TCO), the Marine Air Command and Control System (MACCS), Marine Integrated Logistics System (MILOGS), Marine Flexible Fire Support System (FIREFLEX) and the Marine Air Ground Intelligence System (MAGIS).

The Marine Corps' move to fully automated systems is going to require careful evolution from the existing communications system. This is emphasized by MajGen. W.R. Etnyre, USMC, CG, Marine Corps Combat Development Command, in the MTACCS Operational Concept.

> Successful implementation of an expeditionary MTACCS depends on development and fielding of a communications architecture that is capable of passing a large number of digital burst-transmission messages across fewer communications links. The tactical communications architecture of the Marine Corps must, therefore, evolve from a network of functionally dedicated voice channels into a system of information pipelines connecting various elements of the MAGTF..."information pipelines" will allow transmission of messages on any available circuit. This will permit reduction of the large number of dedicated nets which presently make up the MAGTF communications infrastructure and should result in a reduction in the amount of equipment and personnel required to support tactical operations. [Ref. 1]

With such a need, how should the evolution take place? To assist in solving this complicated problem this thesis will address the primary research question "How can the impact of converting voice communications to digital communications be estimated?"

B. PURPOSE AND SCOPE

The purpose of this thesis is to modify the Marine Corps Communications Architecture Analysis Model (MCCAAM), a simulation model designed to evaluate and compare performance of different MAGTF communication architectures, so it can accurately handle digital communications and to demonstrate its usefulness by comparing various partially digital architectures. Users presently define their own architectures through an interactive menu system. By modifying the data bases controlled by this feature, the user will be able to designate digital or voice communications for each net.

For manageability, analysis will be limited to the ground fire support network for a Marine Expeditionary Brigade (MEB). The network will be evaluated using the architecture currently proposed by the USMC. A fixed number of variations will be evaluated based on a limited number of SINCGARS radios, capable of passing both digital and voice traffic. Ultimately we will determine what is the most effective allocation scheme from this predetermined set.

My hope is to increase the utility of MCCAAM, as both a research and management tool, for the development of more efficient and reliable communication architectures.

C. OUTLINE OF THESIS CHAPTERS

Chapter II provides additional background information required to fully understand the problem. It defines specific terms and concepts to include hardware and software found in a USMC digital communications network, and discusses measures of system performance needed to evaluate communication architectures. Chapter II also introduces MCCAAM and gives an overview of the analysis of strictly voice communications performed by Capt Mike West, USMC. [Ref. 2]

Chapter III focuses on solution methodology. It describes the work that needed to be done to solve the current problem. How MCCAAM needed to be modified and how object-oriented simulation made this easy. The requirements and assumptions necessary to modify MCCAAM are also included in this chapter.

Chapter IV, "Analysis Example," discusses the actual experiment performed to analyze the problem, "Given a set of allocation schemes for SINCGARS, what is the best allocation scheme when it is used primarily for digital traffic?" This becomes a realistic problem when limited assets are available and the USMC prefers mixed voice/digital communications. Which nets should be voice and which nets should be digital?

In Chapter V experimental results and output analysis are presented to address the three concepts of model verification, model validation, and output analysis. How did we ensure that the simulation performed as intended? How did we determine that the model represented future USMC communications? What operations research techniques were used to examine and determine the model's true parameters and characteristics?

Finally in Chapter VI, "Summary, Conclusions and Recommendations," the primary research question, "How can the impact of converting voice communications to digital communications be measured?" is answered. What did the results of the experiment actually mean. Are the allocation schemes selected comparable to those selected in the voice-only analysis? Why, or why not? In Chapter VI an appraisal is made of the USMC's evolution towards digital communication. Has the USMC made sound decisions or does the model suggest there is a better way to transition to the future. In closing, conclusions and recommendations about USMC communications and future uses and modifications which can be made to MCCAAM are presented.

II. BACKGROUND INFORMATION

A. DEFINITIONS

Evolution towards digital communications introduces a whole new vocabulary. The USMC is currently developing FM-FM 3-45, Marine Corps Digital Communications Architecture [Ref. 3], to introduce Marines to this new field. The following discussion, excerpted from FM-FM 3-45, presents the terms and concepts necessary to form a basic understanding of digital communications, and the changes to MCCAAM required to evaluate partially digital communications architectures.

Command and control (C2) systems are made up of numerous **command and control facilities (C2FACS)**, users grouped in facilities that are required to gather, transmit, fuse and disseminate information through the MAGTF communications structure. C2FACS vary in size and cover ground, air, combat service support and intelligence operations. Depending on the nature of the communications system, the information will be transferred by either analog or digital signal. An **analog signal** is a continuously varying electromagnetic wave that may be propagated over wire or radio. Its characteristics are determined by the variance in frequency and amplitude of the signal. Voice communications are classified as analog signals. Conversely, **digital signals** consist of discrete pulses of voltage or current which represent binary coded

information. These pulses, referred to as bits, are the nucleus of digital communications. Data carrying capacities of digital communication channels are expressed in bits per second (bps). The discrete nature of a digital signal lends itself to advanced signal processing and makes it easy to combine the signal with other forms of data.

Because the digital signal can be divided into parts, a procedure called **time division multiplexing** can be used. This allows a number of information channels to be assigned to a common circuit at the same time, each transmitting bursts at slightly different points in time. By optimizing circuit usage, fewer nets and therefore fewer assets are required to meet communications needs.

An evolving system using **hybrid**, combined digital and analog, communications will require modems to use analog circuits for data transmission. The **modem**, MODulator/ DEModulator translates the digital signal into a form that is compatible with the analog transmission circuit. The USMC is currently using the Tactical Communications Interface Module (TCIM).

Now that the technique exists for sending digital signals across analog circuits, how are signals assigned to particular circuits? There are three separate methods: circuit switching, message switching and packet switching. The first, **circuit switching**, establishes a circuit on demand for exclusive use between calling and called parties. The circuit

remains reserved for exclusive use by these two parties until the connection is terminated. This method is used in telephone systems. The second, **message switching**, transmits entire messages to a destination once any circuit becomes available. If all lines are busy, the message is stored at the originator then transmitted on the first available circuit. The last, **packet switching**, breaks each message into finite-size packets that are entered into the network on the first available circuits. This optimizes the use of the circuits. Once all packets for a message are received on the other end of the circuit they are reassembled into the message, which is then passed to the receiving terminal.

When information must be passed to multiple receivers and retransmission is impractical, a code called **forward error correction (FEC)** is attached to the data at the transmission point. FEC helps guard against lost or damaged data, conditions that would require retransmission, and allows the receiver to recognize the usable data by identifying start and stop points.

As computers or other data processing devices are introduced and larger amounts of data are passed in the form of files, greater coordination between communication systems is needed. For two **entities**, anything capable of sending or receiving information, to communicate successfully, they must "speak the same language." What is communicated, how it is communicated and when it is communicated must conform to some

mutually acceptable conventions between the entities involved. The conventions are referred to as **protocol**, a set of rules governing the exchange of data between the entities. The key elements of a protocol are syntax, semantics and timing. **Syntax** sets data format and signal levels. **Semantics** addresses control information for coordination and error handling. **Timing** ensures speed matching and sequencing. The protocol is the software which unifies all of the hardware in the communications system.

B. DIGITAL COMMUNICATIONS HARDWARE AND SOFTWARE

For evolution to occur, equipment must be updated and replaced as new techniques and procedures are developed. Advances in these two areas must be made in conjunction with one another if doctrine is going to take advantage of improved technology. This section outlines the new technology represented in the analysis experiment.

SINCGARS is the single channel radio (SCR) which will be used. Recently acquired by the USMC, this VHF-FM radio system is able to transmit analog voice, tactical analog data, and 16 kilobits per second digital data record traffic. The transmission range is similar to that of the AN/VRC-12 family radios. However, its range will be dependent on what type of digital device is connected to it and how the radio is employed. It may be in a backpack configuration producing 10 watts, or in a vehicle producing 50 watts of power. It

improves use of the VHF spectrum by providing 2320 discrete channels vice 920 currently offered. It also offers a re-transmission capability similar to that of the present system. One of the most valuable qualities of SINCGARS is its Electronic Counter-Counter Measure (ECCM) technique, its ability to frequency hop. By putting a random hopping pattern and synchronizing all radios with this pattern, SINCGARS radios can communicate with one another on "one channel" while reducing the effectiveness of the enemy's Electronic Counter Measures (ECM). Operating in the fixed frequency mode, SINCGARS is compatible with all VHF-FM, radios currently in the USMC inventory. It is also compatible with all Communications Security (COMSEC) equipment used by the USMC. [Ref. 3] The technical characteristics for SINCGARS can be found in Appendix C.

To enable the user to send digital information, some sort of digital device must be connected to the radio. The smallest is the AN/PSC-2 digital communications terminal (DCT). It provides the user with point-to-point and netted communications over a variety of military radios and COMSEC equipment. The DCT message processor performs all tasks of format composition, address coding, error control, and error checking, as well as net protocol. [Ref. 3] The technical characteristics for the DCT can be found in Appendix C.

While the DCT is the preferred digital equipment on the move, larger, more stationary headquarters employ an automated

fire support system, the Advanced Field Artillery Tactical Data System (AFATDS). This system facilitates collection and processing of fire support requirements and information using computers and other automated equipment.

To allow AFATDS to utilize SINCGARS the Tactical Control Interface Module (TCIM) is used. The TCIM is an advanced modem that contains appropriate processing and memory capabilities to perform as a front-end communication processor for the Lightweight Computer Unit (LCU), a tactical version of the personal computer. [Ref. 3] The technical characteristics for the TCIM can be found in Appendix C.

New, innovative hardware in a communications network is useless unless it can communicate. The protocol is what makes a variety of communications hardware interoperable. The protocol to be modeled is the MTS Broadcast protocol used with SINCGARS, the TCIM, AFATDS and the DCT.

As outlined in the Marine Tactical System/Technical Interface Data Plan(MTS/TIDP) [Ref. 4], the MTS Broadcast Protocol is best described as Carrier Sensed Multiple Access (CSMA). It does not provide collision detection. The implementation requires each node or command and control facility (C2FAC) to determine a Net Access Delay (NAD) after each successful message broadcast. All nodes compute their NAD simultaneously but independently. Randomness is created in the NAD equation:

$$NAD = 2.12 \text{ seconds} * F$$

by F, a random integer in the range (0-7). [Ref. 5]

Without Collision Detection, if two or more nodes compute the same value, that is also the lowest value computed by all stations, these stations will broadcast their next message simultaneously. Since there is no collision detection, all messages are transmitted to completion. But, the messages will be unreadable by the receiver and will require retransmission. [Ref. 5]

If link level acknowledgement is required, the multiple sending stations set the Time-out Period (TP), the time the sending station waits to receive acknowledgements, based on the message they transmitted. All remaining stations on the net set their Response Hold Delay (RHD), the time a station waits before starting action to send another message, and TP, based on the message they received (FM Capture). If acknowledgement is not received, the sending station automatically retransmits a maximum of two more times, at which time the message is deleted. Without link level acknowledgement, the system deletes messages after one transmission. Figure 1 shows how TP, NAD and Acknowledgement all interact to make up the MTS Broadcast Protocol. [Ref. 5]

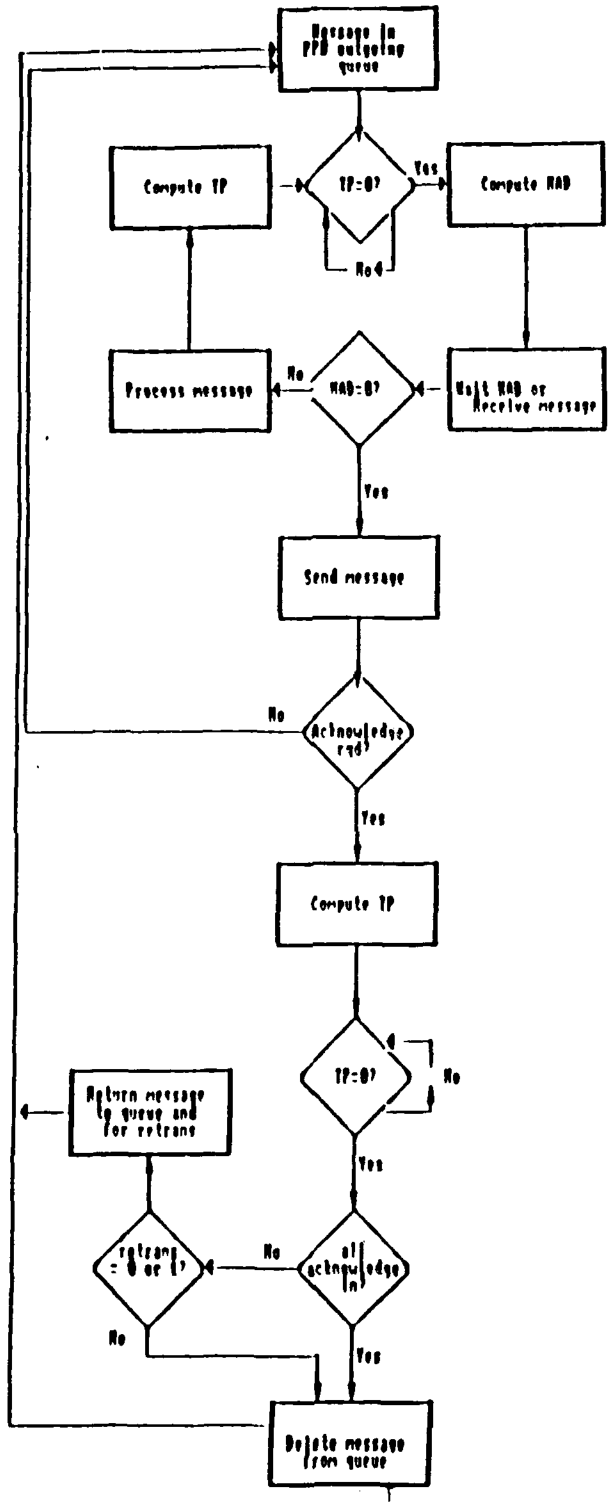


Figure 1. Flowchart of MTS Broadcast Protocol

C. MCCAAM

As the name implies, the model was designed to evaluate various Marine Corps communication architectures based on their ability to perform under a specified traffic workload. An object-oriented simulation model, MCCAAM, uses input datafiles defining nets, units, Broad Operational Subtasks (BOSTs), messages and jammers to build an actual communications architecture. The traffic workload for the model is based on doctrinal messages sent by operational Marine units [Ref. 4] but is defined by the user as he controls the frequency of certain tasks generated by particular units by establishing a "BOST initiation" probability distribution. Specific information on how MCCAAM represents realistic MAGTF message traffic can be found in West's Thesis [Ref. 2] and a paper entitled "Object-Oriented Modeling of the Communications Networks of the MAGTF" [Ref. 6].

In general, the model creates this realistic workload using a "Traffic Generator" and a unique traffic workload paradigm. First the generator selects a Broad Operational Subtask (BOST) to be initiated by one of the units in the architecture. One example of a BOST is a standard call for fire. Each BOST consists of a series of Message Exchange Occurrences (MEOs) that must be performed before the BOST can be considered complete. In accordance with USMC doctrine, each MEO between C2FACs is assigned to a specific net. [Ref.

4] To summarize, each BOST initiated by the traffic generator will ultimately result in a certain amount of use for some or all of the nets in the architecture as C2FACs compete to perform the required MEOs. Figure 2 illustrates the interaction between the "Traffic Generator," the Units and the Radio Net. [Ref 2.]

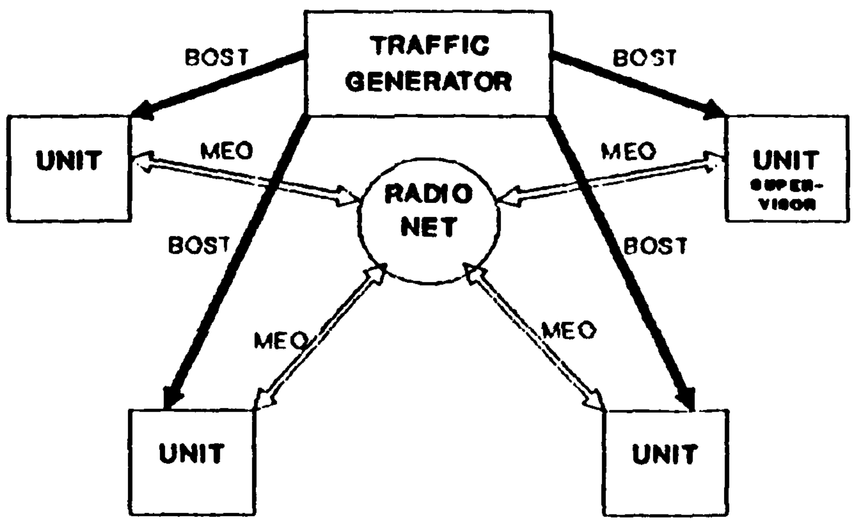


Figure 2. Interaction Between Traffic Generator, Units and Radio Net

Utilizing MCCAAM is a three-step process consisting of Design, Test and Evaluation. Using MCCAAM's Data Base Manager, the user can design his own architecture by defining which units and nets will be involved. He can establish the traffic, the BOSTs and MEOs, to be sent across his network,

and he can define the characteristics of the "Jammers" which will adversely affect communications. He can adjust the "traffic workload" by altering the parameters for the traffic generator. Finally, he sets the parameters for his simulation run. After testing his architecture for a specific instance, MCCAAM provides output to analyze the architecture's efficiency. Figure 3 outlines the three steps for using MCCAAM. [Ref. 2]

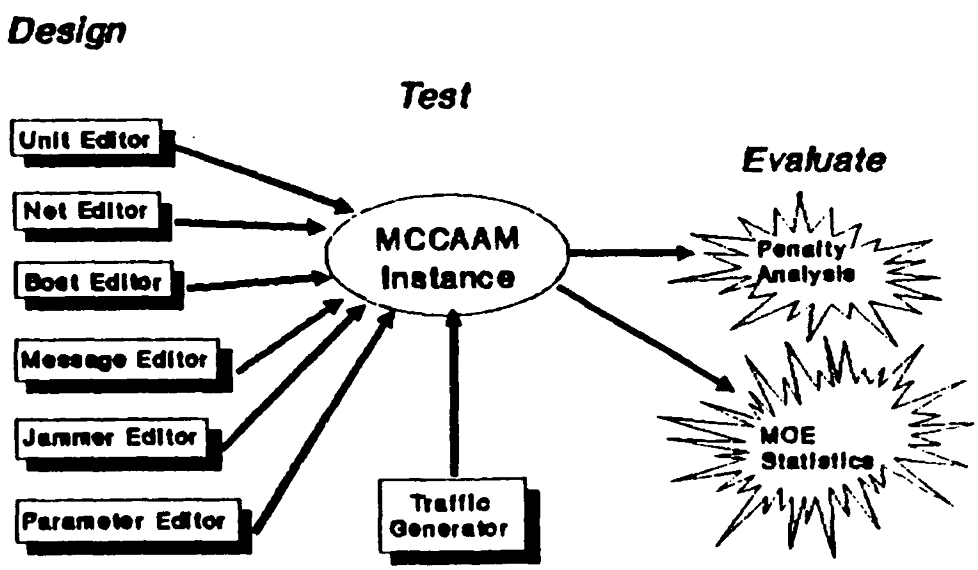


Figure 3. MCCAAM Utilization

Using this output, architecture efficiency can be examined by two separate methods. The first method uses utility theory to aggregate a set of traditional communications measures of effectiveness (MOEs). These MOEs include network

construction, network maintenance, information protection, radio reliability, grade of service, protection from jamming and timeliness. The most common method of aggregating MOEs is to assume a linear combination that results in a single quantity of effectiveness,

$$E = \sum w_i M_i$$

where M is the measure of effectiveness and w is its associated weight. This method can be inaccurate due to many invalid assumptions. [Ref. 2]

To alleviate these problems, West used a variation of this method that summed the weighted values of the user's utility of each of the MOEs: [Ref. 2]

$$E = \sum w_i U_i$$

Weights were established using the Analytical Hierarchal Process as implemented in a commercial software product, Expert Choice, and utilities were determined based on utility curves developed by Von Neumann and Morgenstern (1944).

The second method used to compare individual architectures measures each system's timeliness through a penalty accrual process. Using user defined completion times for each BOST, a one-time penalty is assessed for completion failure. Then,

for a limited period of time, while the BOST remains incomplete, the penalty continues to increase at a user defined penalty accrual rate. The user is provided with a final penalty.

D. PREVIOUS RESEARCH USING MCCAAM

SINCGARS was procured by the USMC as a next generation radio to replace the AN/PRC-77, AN/VRC-12 family of radios. Because of an extremely tight budget and the acquisition process, the USMC could not do a "one-time" replacement of all the older radios. In order to phase the new SINCGARS into the system in an orderly and justified fashion, a plan of attack was needed.

Capt West used MCCAAM to propose a solution to this problem [Ref. 2]. He compared four different schemes for allocating SINCGARS to using the analysis methods in MCCAAM. His experiment considered only voice communications on the ground fire support network of a MEB. Due to the flexibility of MCCAAM, he was able to create four different appearances for this same network, representing the four different allocations of SINCGARS. The first scheme, no SINCGARS, was a baseline to represent the current method of doing business. The second allocated SINCGARS starting at the forward edge of the battle area (FEBA) and continued towards the rear areas. This provided SINCGARS to those units most likely to be in contact, and closest to the jammers. The third provided

SINCGARS to the highest headquarters first and worked downward. This assumed that higher headquarters would have the most important information and therefore needed the most reliable nets. The last scheme allocated SINCGARS to the busiest nets. This plan assumed the improved performance of SINCGARS would be more valuable where the radio would be used most often.

His results indicated that using SINCGARS on the busiest nets allowed the most BOSTS to be completed and generated the highest aggregated measure of effectiveness. However, analysis by penalty rate indicated the network was most efficient when SINCGARS were allocated from the FEBA bank.

This experiment demonstrates the utility of MCCAAM. By designing, testing and then evaluating various architectures using MCCAAM, a potential solution to a real world problem was proposed.

III. SOLUTION METHODOLOGY

A. THE FIDELITY ENHANCEMENT PROCESS

Given MCCAAM and the requirement for a model which can evaluate digital communications, a systematic process was needed to enhance the existing model. The Fidelity Enhancement Process (FEP) developed by Cpt. Charles Chase, USA, is a comprehensive five-step methodology for performing such model upgrades. Implementation of the FEP is portrayed in Figure 4. [Ref. 7]

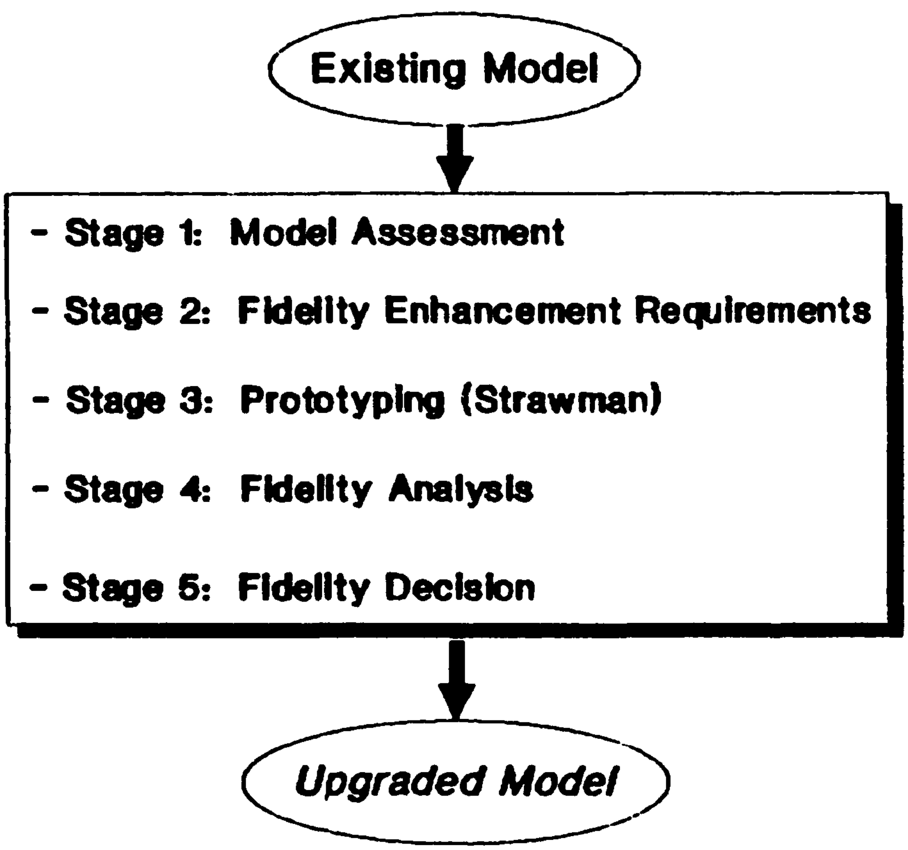


Figure 4. The Fidelity Enhancement Process (FEP)

The Fidelity Enhancement Process is a risk driven approach designed to increase resolution of an existing model. It requires a model written in Object Oriented Simulation language, such as MODSIM II. It also requires a model with an open architecture. The term open architecture implies that

- Operating systems,
- Graphical user interfaces,
- Data base management interfaces,
- Network operations and protocols, and
- Interfaces to presentation graphics programs,

have been standardized to facilitate model migration to improve performance.

Reimplementing existing models on new architectures will no longer require developers to change the model's code. MCCAAM possesses both of these qualities as the FEP was created in conjunction with model development. [Ref. 7]

1. Stage 1--The Model Assessment

The first step of the process is Model Assessment. Establish the foundation for development. What are the risk areas to modification? Logic, algorithms, data, and associated assumptions all determine a models current level of resolution. The second part of assessment is to determine the model upgrade limits. What were the events which generated the need for an upgrade? Were the modifications driven by hardware limitations or the model's capabilities?

2. Stage 2--Fidelity Enhancement Requirements

This is a joint effort by the user and developer of the model to determine the proposed model enhancements and their effect on the risk areas mentioned earlier. Often enhancements will involve the creation of new modules/objects or modification of existing data bases.

3. Stage 3--Prototyping

Prototyping (Strawman) integrates each enhancement into the model such that it can be turned on/off. This form of integration allows all enhancement combinations to be evaluated independently.

4. Stage 4--Fidelity Analysis

Fidelity Analysis examines the costs and benefits of the upgrades. Such costs include performance degradation, data risk, and model sophistication. How much does computing speed increase? What additional data is needed? And what increased level of understanding is required by the user for model utilization? Do the benefits of better answers and increased confidence outweigh the costs? The Fidelity Assessment, the cornerstone of Fidelity analysis, is where all costs and benefits are collected, quantified and assessed. By creating a baseline, an existing model with no enhancements, a topline, with all enhancements implemented, and all combinations in between, a factorial or block experimental design can be used in conjunction with ANOVA techniques to

determine the significance of changes made to the model. [Ref. 6]

5. Stage 5--Fidelity Decision

The final stage of the FEP is the Fidelity Decision. Based on the results of the Fidelity Assessment, a subjective analysis of the model's proposed level of sophistication and the data risk involved to complete the upgrade, a decision is made to execute selected enhancements to the model.

B. PROCESS APPLICATION

The purpose of this thesis was to modify MCCAAM so it could accurately handle digital communications. The FEP served as an excellent guideline for evaluating and performing the necessary model upgrades.

1. Stage 1--The Model Assessment

The USMC's transition to digital communication dictated that MCCAAM's capabilities be upgraded lest the model become obsolete. Because the model was recently developed, its foundation was sound and its boundaries were determined sufficient for the enhancement. The only key risk area which would be affected would be data because of changed message structure and a modified communications architecture. Protocol could be represented using the existing routing scheme and a modified message data base with protocol delays built into message length.

The model's hardware boundaries were determined adequate as the model had previously migrated to a SUN workstation with an upgraded version of MODSIM II.

2. Stage 2--Fidelity Enhancement Requirements

To implement stage II we determined the proposed model enhancements. To accurately represent digital messages with the added protocol considerations, the entire message data base would have to be modified. Each message duration would have to be recalculated considering data transfer rate, message length in bits and time delays due to protocol such as, forward error correction (FEC), time-out period (TP), acknowledgement and net access delay (NAD). Several assumptions were made so that all factors associated with digital communications could be represented by a single "reduced" message duration.

Actual message lengths were taken from the Marine Tactical System/Technical Interface Data Plan Volume IV (MTS/TIDP vol. IV). [Ref. 4] To calculate duration we assumed a data transfer rate of 16 kbps and a protocol with forward error correction and acknowledgement on. A maximum net access delay along with a maximum number of users on the net was also assumed as a "worse case" scenario. Making these assumptions, message duration or net time used was calculated as:

$$\text{message duration} = (2 * \text{message length})/\text{transfer rate} + TP + NAD$$

where,

Timeout
period (TP) = (# users * RHD)+(2 * .01 * message length)

The response hold delay (RHD), the amount of time all stations must wait before starting action to send another message, is a constant, 3.059 seconds for the KY 57/58 crypto device, the device used with SINCGARS. Note all message lengths are doubled as a result of FEC. The maximum NAD is also a constant, 14.84 seconds. This is the result of a random number of seven being chosen. [Ref. 5] We determined MCCAAM's message handling capabilities sufficient to simulate digital communications with the upgraded message data base.

We also wanted our model to represent future USMC Communications. Transition to digital communication meant new radios had to be added to the architecture and all radios had to be classified as carrying digital or voice traffic. Here we assumed SINCGARS would primarily be used for digital communication and the PRC-77 would primarily be used for voice. To ensure compatibility with the Marine Corps Tactical Communications Architecture (MCTCA) [Ref. 8], USMC doctrine, several nets had to be added to the net data base. Finally, to keep data bases consistent, net connectivity had to be verified for each unit inside the unit data base.

3. <u>Stage 3--Prototyping</u>

During stage III, the enhancement was added to the model and evaluated for validity. First a baseline was set. This was a new architecture composed entirely of SINCGARS operating in the voice mode. MCCAAM remained unchanged and message lengths represented voice traffic. The enhancement changed all message durations to digital length to include protocol delays. To ensure our architectures would be tested we increased the traffic workload by reducing the BOST interarrival time inside the traffic generator data base. Figure 5 shows the baseline vs. the proposed enhancement.

	Baseline	Enhancement
Model	MCCAAM	MCCAAM
Radios	SINCGARS	SINCGARS
Message Length	Voice	Digital

Figure 5. Baseline vs. Enhancement

Storing the enhancement as a separate database made independent evaluation straight forward using the organic analysis tools of MCCAAM.

4. Stage 4--Fidelity Analysis

Here we examined the costs and benefits of the enhancements. Costs were minimal as the only change made to MCCAAM was the altered databases. Since MCCAAM was originally developed to allow the user to input his architecture by using the Data Base Manager, the model performed as designed. However, in order for the user to input a digital architecture, some knowledge is required on his part. He must know the data transfer rates of the digital equipment used, the bit length of the messages sent, and how his specific protocol will effect the amount of net time which is used sending each message. Obviously, he must understand the basics of his architecture such as units involved and net connectivity. Additionally, the enhancements did not cause any performance degradation or add greatly to the model's sophistication.

Benefits? By virtue of a little research, knowledge and database manipulation, the user can explore a whole new field of communications. Generally, the benefits will outweigh the costs. But, because MCCAAM itself is not being changed significantly, each user must make that decision for himself based on the amount of database manipulation required.

One of the key reasons for switching to digital communications is efficiency. Key indicators of an architecture's improved efficiency are increased throughput and reduced network delay. For Fidelity Assessment, we examined both of these areas. To measure throughput we

compared the number of BOSTs completed per unit time for each option. To measure network delay we compared the penalty assessed per unit time for each option. The penalty is a good measure of delay because it is assessed once but continues to accumulate at a constant rate while the BOST remains incomplete.

To evaluate our proposed changes we simulated each architecture for 9000 minutes or 6.25 days. Data were collected recording the number of BOSTs completed and the change in penalty level for each 90 minute increment. Based on analysis of initial conditions, the first 1000 minutes were considered a "warm-up" period and thus omitted. [Ref. 9]

To ensure independent, identically distributed (iid) samples, we performed "batched means" on our data collected for each 90 minute increment. Our batch size was set at three giving us 30 iid samples for both, BOSTs completed and change in penalty level. [Ref. 9] These data were then checked for normality using AGSS, a graphical statistical analysis program on the mainframe computer at the Naval Postgraduate School. The Normal Probability plots with 95% Kolmogorov-Smirnov bounds for BOST and penalty data for both baseline and enhanced runs can be found in Appendix D.

Convinced the data within each sample were approximately Normal, iid, we next examined the assumption of equal population variances before performing an ANOVA to test the null hypothesis that the mean BOST completion/90 min for the

baseline was equal to the mean BOST completion/90 min for the enhancement. The boxplots in Figure 6 below show that this is not a reasonable assumption, so a Kruskal-Wallis Non-parametric test for equal location parameters was conducted instead. The results of our test were significant (p = 1.9819E-10), indicating a difference in the BOST completion rates. [Ref. 10] Examination of the box plot in Figure 6 illustrates a much higher BOST completion rate or throughput for our enhancement.

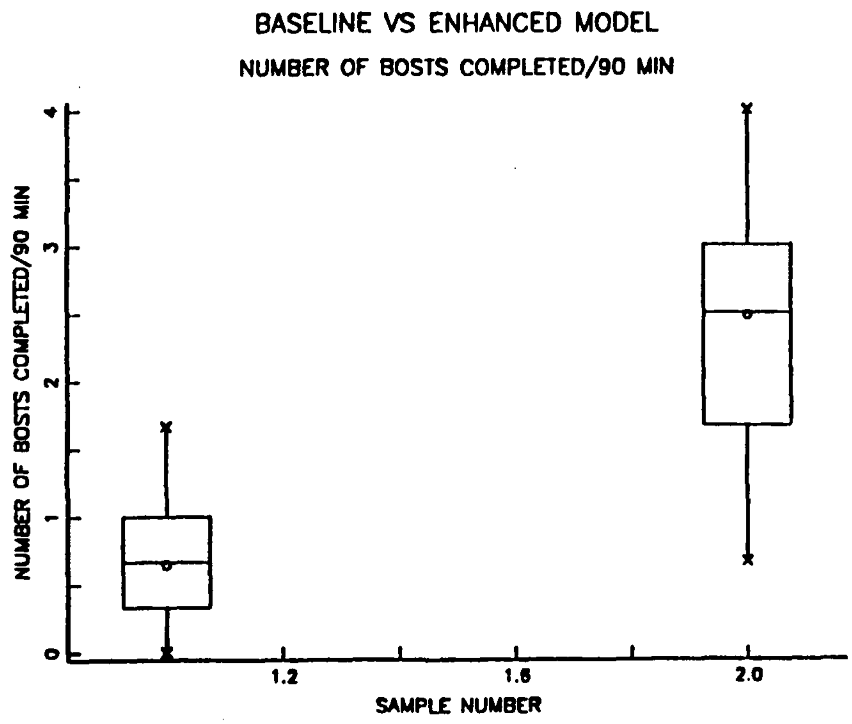


Figure 6. BOST Completion Rate: Baseline vs. Enhancement

We also performed a Kruskal-Wallis test to examine the null hypothesis that the mean change in penalty level/90 min

for the baseline was equal to that of the enhancement. This test was also significant (p = 2.6047E-4), indicating a difference in the penalty rates. The box plot in Figure 7 illustrates a much lower penalty rate or network delay for our enhancement.

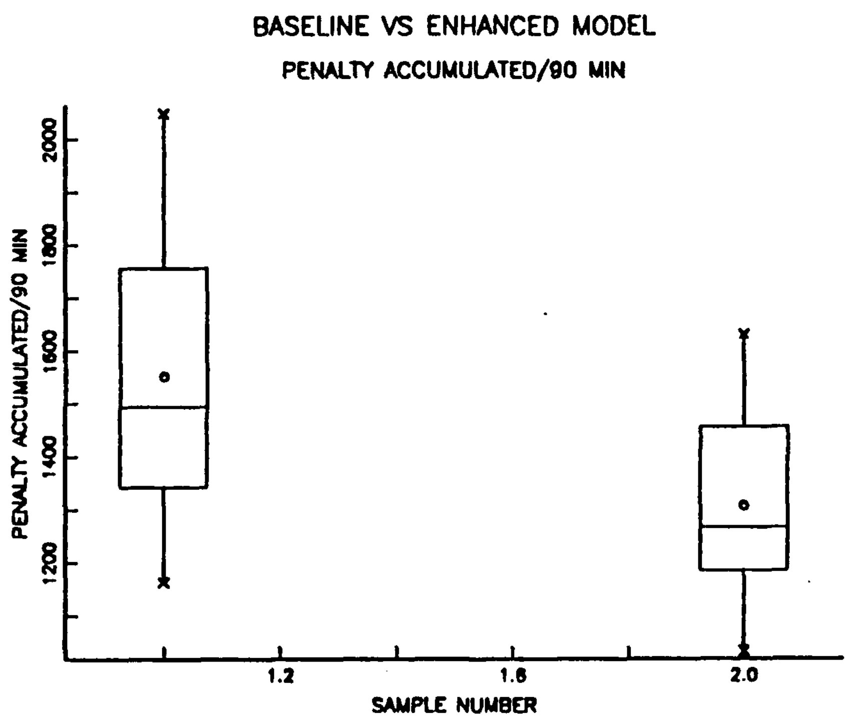


Figure 7. Penalty Rate: Baseline vs. Enhancement

The grand means for our Batched Means analysis are found in Table 1. The increased throughput and reduced network delay for the enhancement indicated that digital communications could be simulated on MCCAAM.

TABLE 1

GRAND MEANS: BASELINE VS. ENHANCEMENT

	Baseline	Enhancement
BOST completed/90 min	0.64444	2.4778
Penalty level/90 min	1550.7	1306.1

5. Stage 5--Fidelity Decision

Based on the results of the Fidelity Analysis, the Fidelity Decision was made. Making the prescribed enhancements to MCCAAM would provide the degree of resolution necessary for measuring and evaluating separate aspects of digital or partially digital networks.

IV. ANALYSIS EXAMPLE

A. EXPERIMENTAL DESIGN

To validate our improved version of MCCAAM, we designed an experiment involving three separate, partially digital communications architectures. The problem statement was, "Given a set of allocation schemes for SINCGARS, what is the best allocation scheme when it is used primarily for digital traffic?" This becomes a realistic problem when limited assets are available and the USMC prefers mixed digital/voice communications. Which nets should be voice and which nets should be digital?

Step one was selecting the architecture to be evaluated. After speaking with Capt Noel of the Systems Integration Branch of the Marine Systems Command [Ref. 11], we decided that the architecture should be consistent with the Marine Corps Tactical Communications Architecture (MCTCA) [Ref. 8] with nets added to facilitate digital/voice communication.

Step 2 was determining the three SINCGARS allocation schemes to be used within the architecture. By designating certain nets as digital or voice, the subscribers to those nets would be issued either SINCGARS or PRC-77s, a fixed frequency radio.

A quick review of MCCAAM's five databases helps to clarify this decision. Within MCCAAM there are message, net, unit,

BOST and jammer databases. The message database defines the actual duration of the message or MEO to be sent. The net database classifies each particular net and designates a radio type to be used on that net. The unit data base dictates which nets each unit will monitor. The BOST data base assigns messages to specific nets. Finally the jammer database lists the location and range of the jammers simulated by the model. Figure 8 lists the databases and shows how they tie all aspects of the model together.

	Databases
Message →	Message duration
Net →	Nets ⇔ Radio type
Unit →	Units ⇔ Nets
BOST →	Messages ⇔ Nets
Jammer →	Location/Range

Figure 8. MCCAAM Databases

Note, in three databases which relate objects to one another, net, unit and BOST, the net object is found on all three. The net object ties all other objects of the model

together. So, by designating nets as digital or voice, radio types are assigned and issued to units according to which nets that unit monitors. Additionally, message lengths can be determined based on which nets they will be transmitted across.

Having decided to designate nets digital or voice, the three allocation schemes were determined. Initially the architecture was assessed and nets were designated as variable or constant. Some nets were held constant while others varied to represent the three separate allocation schemes. The allocation schemes for our analysis example can be found in Appendix B. This was deemed appropriate because the USMC will not have a tactical communications network consisting entirely of digital devices. All constant nets were designated as voice and used either the PRC-77 or HF radio as per doctrine. Variable nets used either SINCGARS primarily for digital traffic or PRC-77s primarily for voice traffic.

1. <u>Allocation Scheme 1--Baseline</u>

This configuration set all variable nets as digital. This required a larger number of SINCGARS, but by designating all variable nets as digital, it gave us results to compare the other two allocation schemes against.

2. <u>Allocation Scheme 2--Higher Headquarters</u>

The second allocation scheme designated the higher headquarters (HHQ) nets, all nets found at the infantry battalion level and above, as digital. This required fewer

SINCGARS, but forced traffic not on these nets to be sent by voice equipment.

3. Allocation Scheme 3--Forward Edge of the Battle Area

Our final scheme designated those nets being utilized closest to the forward edge of the battle area (FEBA) as digital. Here we classified those nets at the infantry battalion level and below as FEBA nets. Again, this required fewer SINCGARS, but also forced traffic not on these nets to be sent by voice equipment.

It also is important to note that the message data base required to support this allocation scheme corresponds exactly to the MTS/TIDP vol. IV. [Ref. 4] Consequently, this allocation scheme is most representative of USMC doctrine.

B. THE EXPERIMENT

The experiment itself involved running three independent simulations utilizing MCCAAM. All three allocation schemes were simulated once each for 9000 minutes or 6.25 days. To keep the replications consistent, the "model run data" and "traffic generation data" were held constant. So for each simulation run, radio failures as well as jamming were modeled and the traffic workload was held constant. This was done to keep the model as realistic as possible.

V. EXPERIMENTAL RESULTS

A. ANALYSIS TECHNIQUE

To analyze our experimental data, we used the same techniques used during fidelity assessment of the FEP. We eliminated the initial conditions from our simulation runs and batched our means to ensure random iid samples. We then calculated grand means to numerically compare the efficiency of our three separate partially digital communications architectures by focusing on throughput and network delay. [Ref. 9] To demonstrate differences, we created multiple sample box plots for BOST completion rate and penalty rate. As output, MCCAAM provided the analysis results for each run. See Appendix A for results of the three experimental runs.

B. EXPERIMENTAL RUNS

The results from the three experimental runs revealed that the Baseline architecture had the lowest penalty rate and the highest BOST completion rate. Stated differently, it had the least amount of network delay and the greatest throughput. Actually, we expected our baseline architecture to yield the best results. This seems logical because all variable nets in the baseline scheme were designated as digital.

The most inefficient architecture used the HHQ allocation scheme. It had the highest penalty rate and the lowest BOST

completion rate, indicating the largest network delay and the smallest throughput.

The architecture using the FEBA allocation scheme fell between the two extremes. However, both its penalty rate and BOST completion rate were closer to the Baseline scheme indicating a similar efficiency level for these two configurations. Table 2 gives a numerical comparison while Figures 9 and 10 graphically depict the differences in BOST completion rate and penalty rate for the three schemes.

TABLE 2

GRAND MEANS: EXPERIMENTAL RUNS

MOE	BL	HHQ	FEBA
BOST completed/90 min	2.611	0.844	2.478
Penalty level/90 min	1256.3	1495.3	1263.2

From our grand means, we note HHQ exhibited a 19.0% increase in penalty rate over the baseline compared to only a 0.5% increase for the FEBA scheme. For throughput, we measured a 67.7% degradation in the HHQ's BOST completion rate compared to the 5.1% degradation for the FEBA. From this comparison, in terms of overall efficiency we would prefer the baseline first. However, we prefer the FEBA scheme over the HHQ scheme since the baseline was established as a standard and is not a viable option.

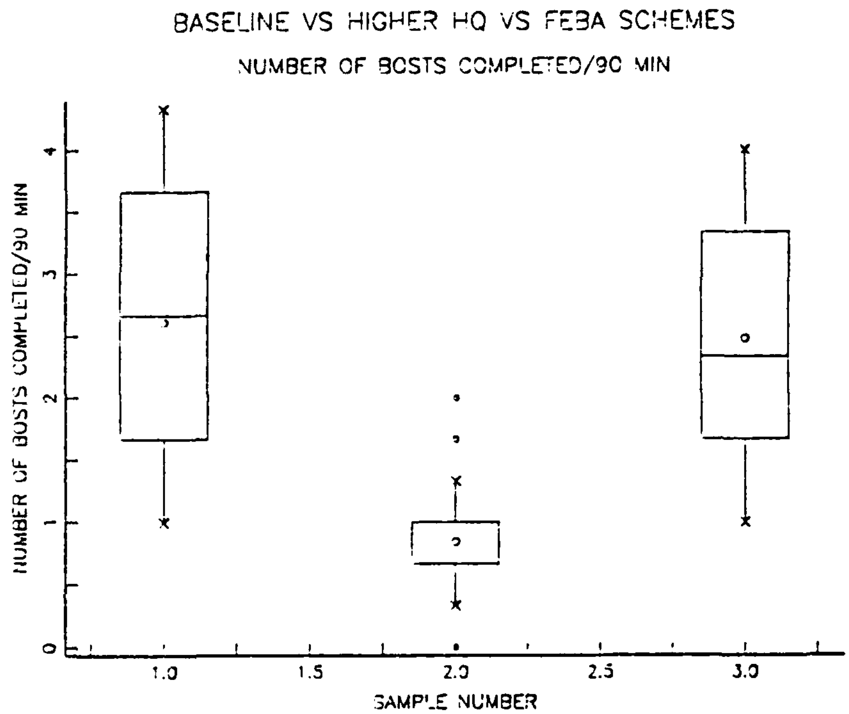


Figure 9. BOST Completion Rate: Experimental Runs

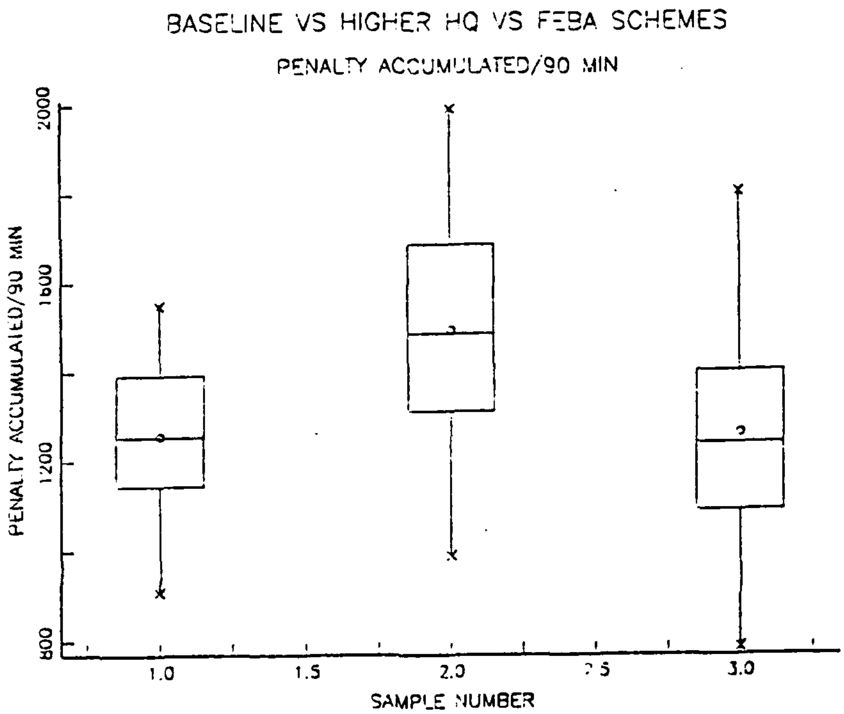


Figure 10. Penalty Rate: Experimental Runs

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Recall the catalyst for this thesis was the USMC's transition to digital communications. Because of this change, they needed a model which could evaluate digital or partially digital networks. From this need we developed our primary research question "How can the impact of converting voice communications to digital communications be measured?" The purpose of the thesis, "to modify MCCAAM, a simulation model designed to evaluate and compare performance of different MAGTF communication architectures, so it can accurately handle digital communications and to demonstrate its usefulness by comparing various partially digital architectures," evolved from the same need.

As a starting point we had MCCAAM, a functioning simulation model and the research of Capt West [Ref. 2] where he evaluated strictly "voice" communication structures using MCCAAM. We also had the research on the Fidelity Enhancement Process, a systematic methodology for modifying existing models developed by Cpt Chase. [Ref. 7] After becoming completely acquainted with these three tools, one research obstacle remained. Extensive study was performed to understand digital communications and how the USMC planned to implement them. FM-FM 3-45 USMC Digital Communications

Architecture (working papers) [Ref. 3], MTS/TIDP vol. IV [Ref. 4], the MCTCA [Ref. 8] and a report on modeling considerations for the MTS Broadcast Protocol provided by Eagle Technologies [Ref. 5] were instrumental documents in constructing the overall "USMC digital communications picture." Upon identifying what was to be modeled, we determined a set of MOEs referencing a report by Kaste, "An experiment to Examine Protocol Performance Over Combat Net Radios." [Ref. 12] We decided that our proposed architectures should be rated based on their throughput and network delay. Fortunately, MCCAAM would provide MOE statistics as output for evaluating both of these areas.

With our plan of action set, step one was to apply the FEP. We determined that digital communications could be simulated by modifying the databases only and that this modification could be made without adversely affecting the model's performance. By adjusting the architecture and ensuring that nets, units and radios were compatible, we could modify the durations of the messages, digital or voice, to coincide with which net they would be transmitted on. All delays associated with the protocol used were included in the "digital" message durations.

Next, to demonstrate its usefulness, we used the "enhanced" MCCAAM to evaluate three separate partially digital architectures. To validate our model, we adhered to USMC

doctrine. This ensured our proposed architectures represented future USMC communications.

B. CONCLUSIONS

Our conclusions are simple and few. First, the FEP is a credible methodology for model enhancement. Second, through the FEP we determined that efficiency as measured by throughput and network delay is an excellent means of measuring the impact of converting from voice to digital communications. Third, that the Baseline allocation scheme is most efficient, but that the FEBA allocation scheme provides a similar high level of efficiency when designing a mixed digital/voice network. Note, according to doctrine, this final conclusion is in concurrence with USMC plans.

C. RECOMMENDATIONS

After developing such a close working relationship with MCCAAM, I must recommend that the model continue to be enhanced and used as a research and development tool. Future enhancements include expanding the BOST and Net databases to apply to other mission areas such as aviation and combat service support, adding amphibious nets to allow the model to be used for amphibious operation planning and adding a routing policy analysis which would help the user evaluate how the traffic was being sent through the network. MCCAAM's potential use to the USMC is virtually unlimited, constrained only by the user's imagination.

After utilizing the FEP, I recommend that it be used to evaluate and implement all future enhancements. Its systematic approach made the whole enhancement process straight forward and very focused.

I recommend that our enhancement method be used to evaluate the effects of changing from voice to digital communications.

Finally, I propose the USMC not allow MCCAAM to "rot on the shelves." This is a valuable planning tool which is under utilized. Its true potential will only be revealed through use, not neglect. Use this valuable tool and continue to improve USMC communications.

APPENDIX A

ANALYSIS RUN DATA

The following pages are the results, as provided by MCCAAM, of the two runs performed as part of the Fidelity Enhancement Process and the three runs performed during the analysis example. The specific values for the global variables are located in the "c3run.dat" file and can be changed using MCCAAM's Data Base Manager.

This is the output information provided by MCCAAM for the run simulating voice message lengths used to analyze the proposed modifications during the Fidelity Enhancement Process. Parameters were set as follows:

(1) Simulation Horizon : 9000.000000

(2) Number of Replications: : 1

(3) Send OBE Traffic ? : FALSE

(4) Model Radio Failures ? : TRUE

(5) Model Jamming ? : TRUE

(6) Traffic Generator Menu

  (1) Steady-state traffic

    (1) Shape Parameter 4.000000

    (2) Initial InterBOST Time 15.000000

    (3) Maximum Number of BOSTs 1000

```
Replication 1 ended at time 9107.918619

PendingList Dump:  SimTime=9107.918619 Number of Objects=0
      PendingList is E M P T Y

Final Penalty for this run is 154709.219097
Final Penalty rate for this run is -9.000000
                                   hope it's 0.0.

Sit in reverent silence for 4 seconds, and be thankful that
another replication has completed without error.
Flushing crapper, and doing TidyAndReset to Penalty/Accum
```

```
NumberOfUnits is              :  51

Number of Bosts initiated was : 588.000000
Number of Bosts completed was : 65.000000

Number of Fixed Frequency Radios in use was :0
Number of Sincgars  Radios in use was       :96

Number of Fixed Frequency Radios not used was :0
Number of Sincgars Radios not used was        :128
```

```
TotalCompletsP  : 0
TotalAttemptsP  : 0

TotalCompletsS  : 10652
TotalAttemptsS  : 10969

NO Fixed Frequency radios used in this run ...

Avg message time for Sincgars  Radios was     :  169.476824

Avg wait time for Sincgars  Radios was        :  56.504656
```

This is the output information provided by MCCAAM for the run simulating digital message lengths used to analyze the proposed modifications during the Fidelity Enhancement Process. Parameters were set as follows:

```
(1)  Simulation Horizon          :  9000.000000

(2)  Number of Replications:     :  1

(3)  Send OBE Traffic ?          :  FALSE

(4)  Model Radio Failures ?      :  TRUE

(5)  Model Jamming ?             :  TRUE

(6)  Traffic Generator Menu

     (1)  Steady-state traffic

          (1)  Shape Parameter                  4.000000

          (2)  Initial InterBOST Time           15.000000

          (3)  Maximum Number of BOSTs          1000
```

```
Replication 1 ended at time 9107.918619

PendingList Dump:  SimTime=9107.918619 Number of Objects=0
      PendingList is E M P T Y

Final Penalty for this run is 129918.621859
Final Penalty rate for this run is -6.000000
                                   hope it's 0.0.

Sit in reverent silence for 4 seconds, and be thankful that
another replication has completed without error.
Flushing crapper, and doing TidyAndReset to Penalty/Accum
```

```
NumberOfUnits is              :  51

Number of Bosts initiated was : 588.000000
Number of Bosts completed was : 249.000000

Number of Fixed Frequency Radios in use was :0
Number of Sincgars  Radios in use was       :97

Number of Fixed Frequency Radios not used was :0
Number of Sincgars Radios not used was        :127
```

```
TotalCompletsP  : 0
TotalAttemptsP  : 0

TotalCompletsS  : 12544
TotalAttemptsS  : 13032

NO Fixed Frequency radios used in this run ...

Avg message time for Sincgars  Radios was     :  94.640764

Avg wait time for Sincgars  Radios was        :  60.375215
```

This is the output information provided by MCCAAM for the run simulating our BASELINE allocation scheme used in the architecture comparison to demonstrate the enhanced model's usefulness. Parameters were set as follows:

```
(1)  Simulation Horizon          :  9000.000000

(2)  Number of Replications:     :  1

(3)  Send OBE Traffic ?          :  FALSE

(4)  Model Radio Failures ?      :  TRUE

(5)  Model Jamming ?             :  TRUE

(6)  Traffic Generator Menu

     (1)  Steady-state traffic

          (1)  Shape Parameter               4.000000

          (2)  Initial InterBOST Time        15.000000

          (3)  Maximum Number of BOSTs       1000
```

```
Replication 1 ended at time 9107.918619

PendingList Dump:  SimTime=9107.918619 Number of Objects=0
      PendingList is E M P T Y

Final Penalty for this run is 125232.066624
Final Penalty rate for this run is -9.000000
                                           hope it's 0.0.

Sit in reverent silence for 4 seconds, and be thankful that
another replication has completed without error.
Flushing crapper, and doing TidyAndReset to Penalty/Accum
```

```
NumberOfUnits is                :  51

Number of Bosts initiated was : 588.000000
Number of Bosts completed was : 258.000000

Number of Fixed Frequency Radios in use was :0
Number of Sincgars  Radios in use was       :102

Number of Fixed Frequency Radios not used was :37
Number of Sincgars Radios not used was        :86
```

```
TotalCompletsP  : 0
TotalAttemptsP  : 0

TotalCompletsS  : 12816
TotalAttemptsS  : 13331

NO Fixed Frequency radios used in this run ...

Avg message time for Sincgars  Radios was     :  91.256254

Avg wait time for Sincgars  Radios was        :  58.068682
```

This is the output information provided by MCCAAM for the run simulating our HHQ allocation scheme used in the architecture comparison to demonstrate the enhanced model's usefulness. Parameters were set as follows:

```
(1)  Simulation Horizon          :  9000.000000

(2)  Number of Replications:     :  1

(3)  Send OBE Traffic ?          :  FALSE

(4)  Model Radio Failures ?      :  TRUE

(5)  Model Jamming ?             :  TRUE

(6)  Traffic Generator Menu

     (1)  Steady-state traffic

          (1)  Shape Parameter                 4.000000

          (2)  Initial InterBOST Time          15.000000

          (3)  Maximum Number of BOSTs         1000
```

```
Replication 1 ended at time 9107.918619

PendingList Dump:  SimTime=9107.918619 Number of Objects=0
      PendingList is E M P T Y

Final Penalty for this run is 150202.980525
Final Penalty rate for this run is -9.000000
                                     hope it's 0.0.

Sit in reverent silence for 4 seconds, and be thankful that
another replication has completed without error.
Flushing crapper, and doing TidyAndReset to Penalty/Accum
```

```
NumberOfUnits is                  :  51

Number of Bosts initiated was : 588.000000
Number of Bosts completed was : 81.000000

Number of Fixed Frequency Radios in use was :49
Number of Sincgars  Radios in use was       :53

Number of Fixed Frequency Radios not used was :62
Number of Sincgars Radios not used was        :60
```

```
TotalCompletsP  : 3415
TotalAttemptsP  : 3649

TotalCompletsS  : 7117
TotalAttemptsS  : 7425

Avg message time for Fixed Frequency Radios was : 132.324851

Avg wait time for Fixed Frequency Radios was : 40.247538

Avg message time for Sincgars  Radios was    :  145.723456

Avg wait time for Sincgars  Radios was       :  61.507770
```

This is the output information provided by MCCAAM for the run simulating our FEBA allocation scheme used in the architecture comparison to demonstrate the enhanced model's usefulness. Parameters were set as follows:

```
(1)  Simulation Horizon          :  9000.000000

(2)  Number of Replications:     :  1

(3)  Send OBE Traffic ?          :  FALSE

(4)  Model Radio Failures ?      :  TRUE

(5)  Model Jamming ?             :  TRUE

(6)  Traffic Generator Menu

     (1)  Steady-state traffic

          (1)  Shape Parameter                  4.000000

          (2)  Initial InterBOST Time           15.000000

          (3)  Maximum Number of BOSTs          1000
```

```
Replication 1 ended at time 9107.918619

PendingList Dump:  SimTime=9107.918619 Number of Objects=0
      PendingList is E M P T Y

Final Penalty for this run is 127979.050293
Final Penalty rate for this run is -9.000000
                                   hope it's 0.0.

Sit in reverent silence for 4 seconds, and be thankful that
another replication has completed without error.
Flushing crapper, and doing TidyAndReset to Penalty/Accum
```

```
NumberOfUnits is               :  51

Number of Bosts initiated was : 588.000000
Number of Bosts completed was : 242.000000

Number of Fixed Frequency Radios in use was :14
Number of Sincgars  Radios in use was       :88

Number of Fixed Frequency Radios not used was :47
Number of Sincgars Radios not used was        :66
```

```
TotalCompletsP  : 1116
TotalAttemptsP  : 1230

TotalCompletsS  : 10137
TotalAttemptsS  : 10472

Avg message time for Fixed Frequency Radios was : 80.666907

Avg wait time for Fixed Frequency Radios was : 43.891159

Avg message time for Sincgars  Radios was    :  88.176792

Avg wait time for Sincgars  Radios was       :  54.821498
```

APPENDIX B

RADIO ALLOCATIONS

The following table shows how the nets in the architecture were designated for each of the two runs performed as part of the Fidelity Enhancement Process and the three runs performed during the analysis example. Note, some radios were held constant according to doctrine to simulate the reality that not all nets would become digital. All radios in the FEP runs were designated as SINCGARS to test the effect of digital versus voice message durations. For the three analysis example runs, PRC-77 and HF radios were used primarily to pass voice traffic while SINCGARS radios were used primarily to pass digital traffic.

Key: 0 PRC-77 radios
1 SINCGARS radios
2 HF radios

CONSTANT NETS	FEP VOICE	FEP DIGITAL	BASE LINE	HHQ	FEBA
MEBCSS	1	1	2	2	2
MEBCOMMCOORD	1	1	0	0	0
MEBCRITICOMM	1	1	0	0	0
MEBINTEL	1	1	2	2	2
ECMCONTROL	1	1	0	0	0
INFREGTCOMMCOORD	1	1	0	0	0
TAR/HR	1	1	2	2	2
MEDBNEVACCOORDAIR	1	1	0	0	0

CONSTANT NETS	FEP VOICE	FEP DIGITAL	BASE LINE	HHQ	FEBA
INFBNTACPLOCAL	1	1	0	0	0
INFCOCMD	1	1	0	0	0
INFPLTCMD	1	1	0	0	0
VARIABLE NETS					
MEBTAC1	1	1	1	1	0
MEBTAC2	1	1	1	1	0
MEBALERTBRDCST	1	1	1	1	0
INFREGTCMD	1	1	1	1	0
INFREGTTAC	1	1	1	1	0
INFREGTINTEL	1	1	1	1	0
INFREGTFSC	1	1	1	1	0
ARTYBNCOF	1	1	1	1	1
ARTYBNCMD	1	1	1	1	1
ARTYBNFD	1	1	1	1	1
INFBNTAC1	1	1	1	1	1
INFBNTAC2	1	1	0	0	1
INFBNMORTAR	1	1	1	0	1
ARTYBTRYCOF	1	1	1	0	1
ARTYBTRYCMD	1	1	1	0	1

APPENDIX C

TECHNICAL CHARACTERISTICS

The following pages list the technical characteristics for the communications equipment addressed in Chapter II.B. Additional information can be found in FM-FM 3-45 Marine Corps Digital Communications Architecture

(SINCGARS-V) Single Channel Ground and Airborne Radio System

Type Modulation:	FM
Type Transmission:	Voice, data
Frequency Range:	30.0 - 87.975 MHz (VHF)
Frequency Entry:	Via keyboard
Freq Hop Preset:	6 nets
Number of Channels:	2320
Channel Spacing:	25kHz
Preset Channels:	6 auto, 1 man/1 cue
Operating Modes:	Single Channel; freq hopping with internal ECCM
RF Power Output:	5 watts, 40 watts with PA
Range:	(Data/Voice)
Manpack:	4.5 km/8 km
Vehicular:	20 km/35 km
Aircraft:	20 km/35 km
Size (Manpack):	Length--11.5"; Width--9.3"; Height--3.3"
Weight (Manpack):	18.3 lbs includes battery
Cube (Manpack):	1 ft(cubed)

Power:	
Manpack:	12 volt primary battery
Vehicle:	22-32 VDC per MIL-STD-1275
Aircraft:	22-32 VDC per MIL-STD-704

AN/PSC-2, Digital Communications Terminal (DCT)

Size:	Length--8.8"; Width--6.9"; Height--1.6"
Weight:	5 lbs
Cube:	1 ft(cubed)
Power:	Self-contained Lithium battery 9V at 8 Amp hours; External 115 VAC with optional adapter; 28 VDC vehicle power with optional adapter
Type Transmission:	Half duplex digital
Type Interface:	FSK, Digital baseband, and MIL-STD-188C
Transmission Rate:	175, 150, 300, 600, 1200, 2400, 8000, 9600 or 16000 bps
Memory:	128K Bytes
Display:	5" x 7" LED Dot Matrix
Comm Protocol:	MTS Broadcast
Physical Interface:	MIL-STD-188-114

TCIM, Tactical Communications Interface Module

Size:

External TCIM: Length--16"; Width--8"; Height--1.6"

Internal TCIM: Standard full-length PC/AT card size

Weight:

External TCIM: 3.8 lbs

Internal TCIM: 0.75 lbs

Communications Interfaces (Programmable):

Channel 1:

KY-68, TA-1034, KG-84(DLED)

AN/GYC-7, ULMS

SB-3614

EPUU JTTDS

4-wire: FSK-188C; FSK-188B; STANAG 4202(ANNEX A); Condition Diphase

Protocols: Maneuver Control System (MCS) Circuit Switch protocol; Marine Tactical System (MTS) TIDP Mode VII protocol; X.25

Channel 2:

Combat Net Radio (CNR); VRC-12 and PRC-77;

SINCGARS; GRC-193, GRC-213, PRC-104

KY-57

2-wire: FSK-188C; FSK-188B; STANAG 4204(Annex A); Condition Diphase

Protocol: MCS CNR protocol; MTS TIDP CNR protocol: MIL-STD-188-110A

Power:

Input Voltage:

External TCIM: 18-36 VDC

Internal TCIM: +/- 5 volts (derived from host computer)

Consumption:

External TCIM: 15 watts max

Internal TCIM: 12 watts max

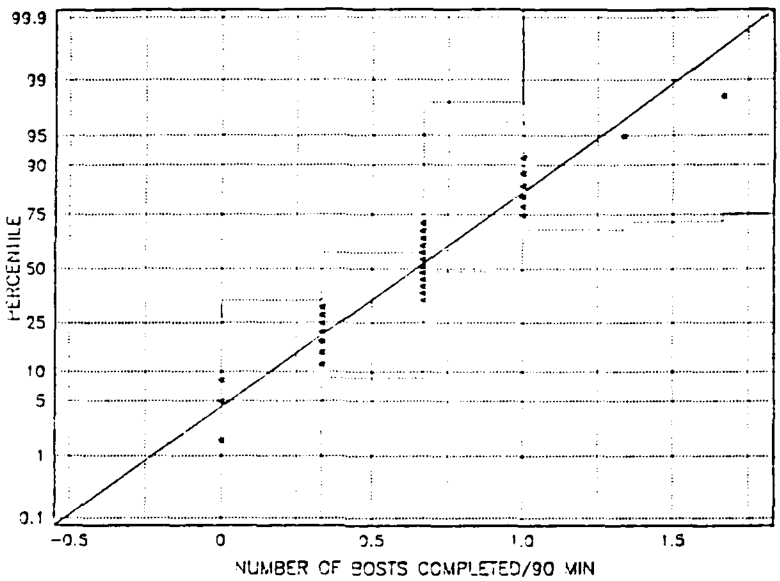
APPENDIX D

NORMAL PROBABILITY PLOTS

The following pages are the normal probability plots from AGSS used to determine the normality of the batched means for BOST completion rate and penalty rate for both the Baseline and Enhanced runs used during fidelity analysis of the FEP.

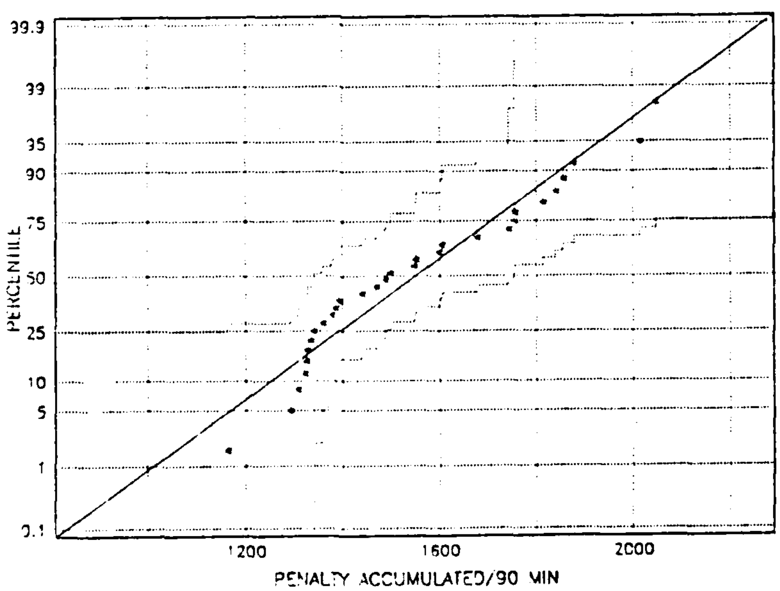
BASELINE MODEL

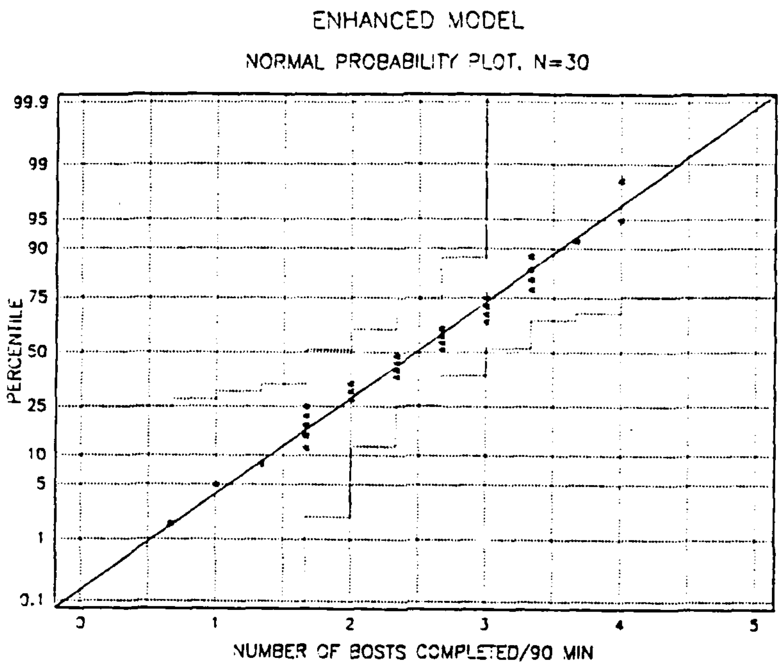
NORMAL PROBABILITY PLOT, N=30

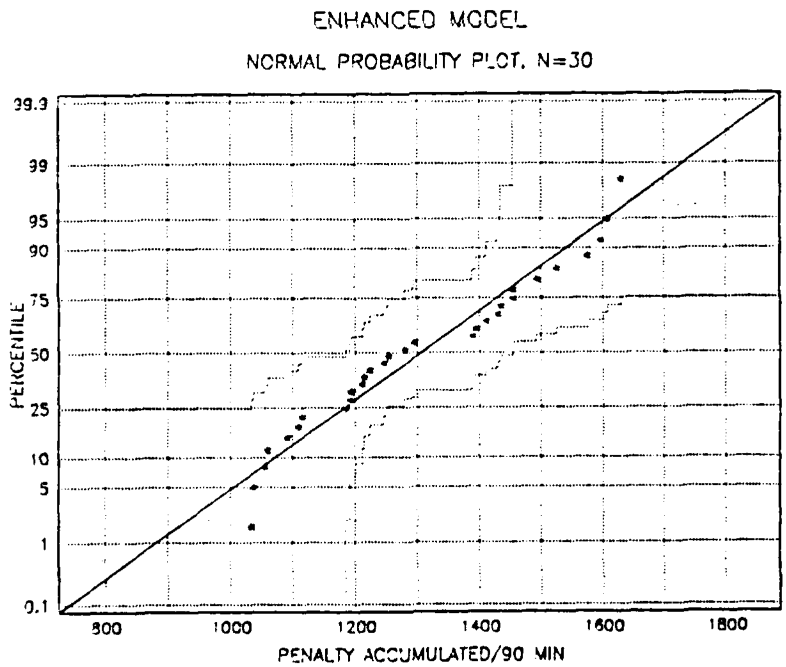


BASELINE MODEL

NORMAL PROBABILITY PLOT, N=30




ENHANCED MODEL
NORMAL PROBABILITY PLOT, N=30
PERCENTILE
99.9
99
95
90
75
50
25
10
5
1
0.1
0
1
2
3
4
5
NUMBER OF BOSTS COMPLETED/90 MIN


ENHANCED MODEL
NORMAL PROBABILITY PLOT, N=30
PERCENTILE
99.9
99
95
90
75
50
25
10
5
1
0.1
800
1000
1200
1400
1600
1800
PENALTY ACCUMULATED/90 MIN

APPENDIX E

LIST OF ABBREVIATIONS AND ACRONYMS

AFATDS	Advanced Field Artillery Tactical Data System
AGSS	A Graphical Statistical System
BOST	Broad Operational Sub Task
bps	bits per second
C2	Command and Control
C2FAC	Command and Control Facility
COMSEC	Communications Security
CSMA	Carrier Sensed Multiple Access
DCT	Digital Communications Terminal
ECCM	Electronic Counter Counter Measures
ECM	Electronic Counter Measures
FEBA	Forward Edge of the Battle Area
FEC	Forward Error Correction
FEP	Fidelity Enhancement Process
FIREFLEX	Marine Flexible Fire Support System
FM	Frequency Modulated
HF	High Frequency
HHQ	Higher Headquarters
LCU	Lightweight Computer Unit
MACCS	Marine Aviation Command and Control System
MAGIS	Marine Air Ground Intelligence System
MAGTF	Marine Air Ground Task Force
MCCAAM	Marine Corps Communications Architecture Analysis Model
MCTCA	Marine Corps Tactical Communications Architecture
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEO	Message Exchange Occurrence
MILOGS	Marine Integrated Logistics System

MOE	Measure of Effectiveness
MTACCS	Marine Tactical Command and Control System
MTS/TIDP	Marine Tactical System/Tactical Interface Design Plan
NAD	Net Access Delay
RHD	Response Hold Delay
SCR	Single Channel Radio
SINCGARS	Single Channel Ground and Airborne Radio System
TCIM	Tactical Control Interface Module
TCO	Tactical Combat Operations
TP	Timeout Period
USMC	United States Marine Corps
VHF	Very High Frequency

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